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The Ohio Academy of Science
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APRIL 28, 29, 30, 1995

GEOLOGY FIELD TRIP GUIDE:

AN UPPER DEVONIAN-LOWER MISSISSIPPIAN SEQUENCE IN CENTRAL OHIO, WITH EMPHASIS ON THE BEDFORD AND BEREA FORMATIONS

8:00 AM, Sunday, April 30, 1995
Arranged by:

LAWRENCE A. KRISSEK and KENNETH P. COATS,
The Ohio State University

Transportation will be in private vehicles leaving from Roush Hall at Otterbein College at 8:00 AM to visit sites in Franklin and Delaware Counties. Lunch is on your own following the field trip.

The Devonian and Lower Mississippian stratigraphic sequence exposed in central and east-central Ohio consists of the Columbus Limestone, the Delaware Limestone, the Olentangy Shale, the Ohio Shale, the Bedford Shale, the Berea Sandstone, and the Sunbury Shale. On this field trip we will examine portions of the above units at three localities: Camp Lazarus, Galena, and Rocky Fork. The Camp Lazarus locality contains exposures of the uppermost Columbus Limestone (low river level permitting), Delaware Limestone, Olentangy Shale, and lower Ohio Shale. The Galena locality contains exposures of the Ohio Shale-Bedford Shale contact and the lower Bedford Shale. The Rocky Fork locality contains exposures of the "Red Bedford", upper Bedford Shale, Berea Sandstone, and Sunbury Shale. During the Late Devonian and Early Mississippian, Ohio was located at approximately 10-15 degrees south latitude, and was covered by the shallow epeiric seas of the Appalachian Basin. The composite section we will observe on this trip represents a major transgressive-regressive sequence deposited in the western part of the basin, and is capped by the subsequent transgressive deposit of the Sunbury Shale. For further information please contact SCOTT BROCKMAN, Ohio Division of Geological Survey, phone 614/265-7054.

The Ohio Academy of Science
1500 W Third Ave Ste 223, Columbus OH 43212-2817, Phone or FAX 614/488-2228.

AN UPPER DEVONIAN-LOWER MISSISSIPPIAN TRANSGRESSIVE-REGRESSIVE CLASTIC SEQUENCE IN CENTRAL OHIO, WITH EMPHASIS ON THE BEDFORD AND BEREA FORMATIONS

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INTRODUCTION

The Devonian and Lower Mississippian stratigraphic sequence exposed in central and east-central Ohio consists of the Columbus Limestone, the Delaware Limestone, the Olentangy Shale, the Ohio Shale, the Bedford Shale, the Berea Sandstone, and the Sunbury Shale (Fig. 1). On this field trip, we will examine portions of the above units at three localities: Camp Lazarus, Galena, and Rocky Fork (Fig. 2).

The Camp Lazarus locality contains exposures of the uppermost Columbus Limestone (low river level permitting), Delaware Limestone, Olentangy Shale, and lower Ohio Shale. The Galena locality contains exposures of the Ohio Shale-Bedford Shale contact and the lower Bedford Shale. The Rocky Fork locality contains exposures of the "Red Bedford", upper Bedford Shale, Berea Sandstone, and Sunbury Shale.

The composite section we will observe on this trip represents a major transgressive-regressive sequence deposited in the western Appalachian Basin, and is capped by the subsequent transgressive deposits of the Sunbury Shale.

<u>Late Devonian-Early Mississippian Paleogeography</u>.--During the Late Devonian and Early Mississippian, Ohio was located at approximately 10-15° south latitude, and was covered by the shallow epeiric seas of the Appalachian Basin (Gutschick and Sandberg, 1983). Major structural elements adjacent to the central Ohio area included the Laurentian Shield to the north, the Acadian orogenic belt to the northeast and east, the Appalachian foreland basinal axis to the east, and the Cincinnati Arch to the west (Fig. 3).

STRATIGRAPHY AND SEDIMENTOLOGY

<u>Columbus and Delaware Limestones</u>.-- The Columbus Limestone and Delaware Limestone cap a thick sequence of relatively "shallow water" Silurian and Devonian carbonates known as the "Big Lime" to area oil and gas well drillers.

SYSTEM	CENTRAL OHIO	NORTHERN OHIO		SOUTHERN OHIO & KENTUCKY	WEST VIRGINIA		WESTERN PENNSYLVANIA
LOWER MISSISSIPPIAN	SUNBURY SHALE	SUNBURY SHALE	ORANGE-VILLE SHALE	SUNBURY SHALE	SUNBURY SHALE		ORANGEVILLE SHALE
	BEREA SANDSTONE	BEREA SANDSTONE		BEREA SANDSTONE	BEREA SANDSTONE		BEREA (CORY) SANDSTONE
	BEDFORD SHALE	BEDFORD SHALE CUSSEWAGO SANDSTONE		BEDFORD SHALE	BEDFORD SHALE		BEDFORD SHALE CUSSEWAGO SANDSTONE
?							
UPPER DEVONIAN	OHIO SHALE	CLEVELAND MBR CHAGRIN MBR HURON MBR		OHIO SHALE	OHIO SHALE	HAMPSHIRE FM CHEMUNG FM	RICEVILLE SHALE CHAGRIN SHALE HURON SHALE
	OLENTANGY SHALE	?OLENTANGY SHALE?		UPPER OLENTANGY FORMATION	JAVA FM WEST FALLS FM SONYEA FM GENESEE FM		JAVA FM WEST FALLS FM
MIDDLE DEVONIAN		PROUT DOLOMITE		"MILLPORT" SHALE	MAHANTANGO FM		HAMILTON GRP
	DELAWARE LST	DELAWARE LST		NOT PRESENT	MARCELLUS SHALE		DELAWARE LST
	COLUMBUS LST	COLUMBUS LST		NOT PRESENT	ONANDAGA FM		COLUMBUS LST

FIG. 1.-- Correlation chart of Middle Devonian to Lower Mississippian units in Ohio, Kentucky, West Virginia, and western Pennsylvania. Compiled from Potter et al. (1983), Sevon and Woodrow (1985), and Sparling (1988).

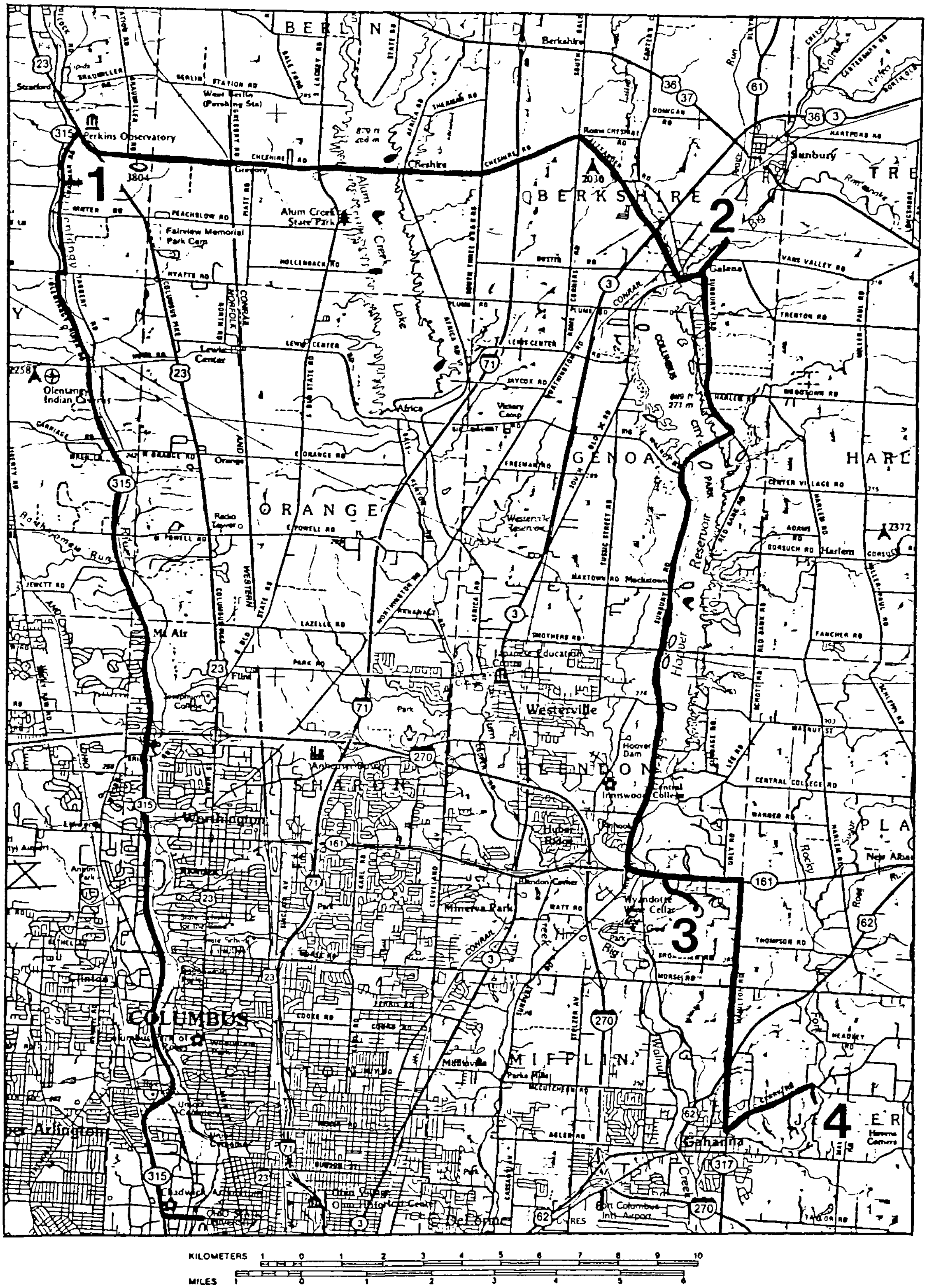

FIG. 2.--Field trip route and location map.

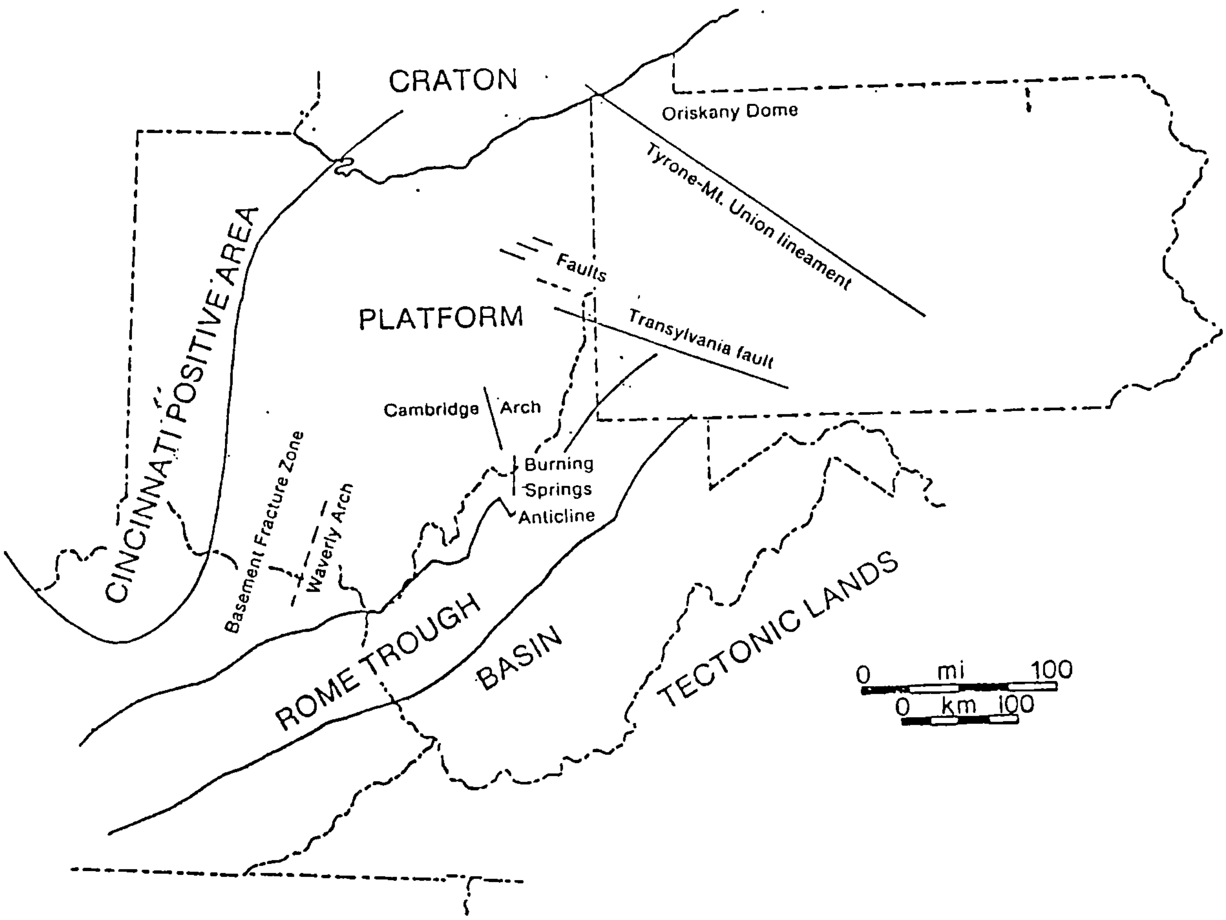

FIG. 3.-- Devonian and Carboniferous structural elements in the northern Appalachian Basin. From Hansen (1984).

The Columbus Limestone is Early to Middle Devonian in age, and is approximately 30 m thick. The unit is named for exposures in the Columbus area; its type section is located at the Marble Cliff quarries along the Scioto River (Tucker, 1969). Westgate (1926) described and divided the Columbus into four members. The Bellepoint is the basal member, and is a massive, thick-bedded, unfossiliferous limestone. Overlying the Bellepoint are two unnamed members: a very fossiliferous coral-rich limestone member, and a fine-grained, thickly bedded, fossiliferous limestone. The upper half of the formation, known as the Klondike Member, is a blue-gray, massive to thinly bedded fossiliferous limestone.

Unconformably overlying the Columbus Limestone is the Delaware Limestone. The Delaware Limestone is named from quarries in the formation at Delaware, Ohio (Westgate, 1926). The Delaware is late Middle Devonian in age, and is approximately 12 m thick. The Delaware generally consists of blue-gray, thinly bedded, cherty, micritic limestone interbedded with thin calcareous shales (Tucker, 1969). The limestone can be divided informally into two members on the basis of lithologies (Stauffer, 1909). The "lower" member is a blue-gray, cherty, argillaceous, sparingly fossiliferous limestone, whereas the "upper" member is a gray, medium-grained, highly fossiliferous limestone (Tucker, 1969).

<u>Olentangy Shale</u>.-- The Olentangy Shale unconformably overlies the Delaware Limestone, and is named for exposures along the Olentangy River at Delaware. It was first described by N. H. Winchell (1874). More recent investigations of the Olentangy Shale were conducted as part of the Eastern Gas Shales Project during the late 1970s. Results of such studies by the Ohio Department of Natural Resources, Division of Geologic Survey are summarized by Gray et al. (1982). The Olentangy Shale represents the initial phase of the clastic influx that eventually filled the Appalachian Basin during the Late Pennsylvanian and/or Early Permian.

The Olentangy Shale is a dark gray to bluish or greenish soft shale interstratified with thin black shales and limestones. On the basis of petrographic analysis of core and outcrop samples from eastern Ohio, Gray et al. (1982) identified three major clastic lithofacies in the Olentangy Shale. These are summarized as follows: dark brownish-black silty shales with thin silt laminae (< 2 mm thick) and burrowing common along silt/clay contacts; dark greenish-gray or olive-black to olive gray silty claystones, with mottling, worm(?) burrows, and rare lenticular laminations; and olive-black to olive gray, homogenous to mottled claystones with locally abundant recrystallized ghosts of microfossils. Carbonates occur in the lower Olentangy Shale as nodular limestone beds and limestone concretions, and are generally composed of one of two lithologies (Gray et al., 1982): homogenous, finely crystalline, laminated limestone and dolomitic limestone, possibly originally micrite, and finely crystalline limestone or dolomitic limestone with abundant broken microfossil ghosts, possibly originally a poorly washed biomicrite. Macrofossils are relatively rare within the unit, but conodonts are common.

In eastern Ohio, the Olentangy Shale consists of quartz, clays, carbonates, potassium feldspar, plagioclase feldspar, and minor pyrite (Gray et al., 1982). Carbonate contents decrease upsection, as recognized by the distribution of limestone beds and concretions in outcrop. Clay mineral assemblages are dominated by illite, with chlorite and mixed-layer clays distributed throughout the region. Kaolinite only occurs in the upper Olentangy Shale, recording introduction of heavily-weathered material late in the interval of deposition of the Olentangy Shale.

The Olentangy Shale averages nine to ten meters in thickness. Ostracode and conodont biostratigraphy (Tillman, 1969) has shown the Olentangy Shale to be both middle Devonian and late Devonian in age, with an unconformity in the middle of the formation. This unconformity is easily recognized on subsurface gamma-ray neutron logs (Gray et al., 1982), but it is rarely evident in outcrops.

Ohio Shale.-- Conformably overlying the Olentangy Shale is the Upper Devonian Ohio Shale. The Ohio Shale was named by E. B. Andrews (1870) for its cliff-forming exposures along the Ohio River in southern Ohio. The shale is generally black, organic-rich, radioactive, fissile, and relatively unfossiliferous. The Ohio Shale is part of a 500 kilometer-wide Devonian shale belt that extends from southern New York to northern Texas (Coats, 1984). Equivalent units in New York and northwestern Pennsylvania include the Conewango, Conneaut, and Canadaway groups; in northeastern and southern Pennsylvania and West Virginia, equivalent units include the Catskill, Hampshire, and Chemung formations (Schwietering, 1970). South and southwest of Ohio, correlative units are the New Albany and Chattanooga shales (Rice et al., 1979). Across northern Ohio, the Ohio Shale is divided into three members; the Huron Shale is the basal member, overlain by the Chagrin Shale Member and capped by the Cleveland Shale Member. The Huron and Cleveland Members are very similar in appearance to the undifferentiated Ohio Shale, which is found in central and southern Ohio. The stratigraphy of the Devonian shales has been extensively studied in the subsurface using natural radioactivity characteristics. Details of such stratigraphy in Ohio are described by Gray et al. (1982).

Average thickness of the Ohio Shale ranges from 80 to 100 meters along the Ohio River. The unit thickens northward to an average of 200 meters in the Columbus area (Hyde, 1953). To the east, toward the depositional center of the Appalachian Basin, reported thicknesses of Devonian shales are 1200 meters or more (Gray et al., 1982). In Athens County, Ohio, the Ohio Shale thickens eastward at a rate of approximately 14 m/km (Sturgeon, 1958).

Lithofacies within the Ohio Shale and equivalent rocks have been outlined in petrographic studies by Gray et al. (1982) in eastern Ohio, and in x-radiographic studies by Nuhfer et al. (1979) in West Virginia and western Virginia. These lithofacies include thinly laminated shales and silty shales, lenticularly laminated silty shales, homogenous to distinctly mottled shales and silty shales, and massive, graded, or cross-bedded siltstones. Carbonates are also present in the Ohio Shale in a variety of forms and compositions, including disseminated as cement, concentrated in thin beds, and precipitated as concretions.

The mineral composition of the Ohio Shale in eastern Ohio has been described by Gray et al. (1982). The whole-rock constituents, listed in order of decreasing average abundance, are quartz, clays, plagioclase feldspar, potassium feldspar, pyrite, and carbonates (calcite/dolomite/ankerite/siderite). Clay mineral assemblages are dominated by illite, with subequal amounts of chlorite, kaolinite, and mixed-layer clays. Kaolinite abundances generally increase upsection through the Ohio Shale, while total carbonate abundances decrease.

The origin of the Devonian black shales has long been debated (Hoover, 1960; Potter et al., 1980; Ettensohn, 1985). The equatorial position of the Appalachian Basin during the Late Devonian, combined with any barriers to circulation, would have promoted the formation of a density-stratified water column. Such a stratified water column has the potential to create disaerobic or anoxic bottom waters. Oxygen-poor conditions appear to have dominated the eastern midcontinent during the Late Devonian, as recorded by significant thicknesses of organic-rich black shales, such as the Ohio Shale (Ettensohn, 1985).

<u>Bedford Shale</u>.-- The Bedford Shale conformably overlies the Ohio Shale. This contact is generally considered to mark the Devonian-Mississippian boundary; however, the exact position of the boundary has been the focus of some debate (de Witt, 1970; Girty, 1912; Conkin and Conkin, 1975; House et al., 1986), and may lie either within the Bedford or above it (Molyneux et al., 1984). The Bedford Shale was named by J. S. Newberry (1870) for a type

locality along Tinker's Creek, a tributary of the Cuyahoga River, near Bedford, Ohio. The shale is unfossiliferous, except for the basal one to two meters in most sections, nonfissile to weakly fissile, and varies in color from blue-gray to chocolate brown to reddish-brown. Thin bioturbated siltstone beds are present locally.

In northern Ohio, the unit has a maximum thickness of 50 meters and is dominated by the reddish-brown mudstone (Pepper et al., 1954). Interpretations of Bedford depositional environments in this area have ranged from subaqueous to subaerial deltaic (Pepper et al., 1954), to barrier bar, lagoonal, and tidal flat (Kohout and Malcuit, 1969), to subaqueous deltaic and marine shelf (Potter et al., 1983; Lewis, 1988). In central and southern Ohio, thicknesses of the Bedford Shale average 30-40 meters. The red mudstone facies thins toward the south; in southern Ohio, the Bedford is dominated by gray mudstone and bedded siltstone (Pepper et al., 1954). Interpretations of the Bedford depositional environments in central and southern Ohio and northern Kentucky have included prodelta and low-gradient delta front, with a significant influence by storm-generated waves (Potter et al., 1983; Pashin and Ettensohn, 1987; Coats, 1988).

The Bedford Formation has been traced from outcrops in Michigan, Ohio and Kentucky into the subsurface in western Pennsylvania, West Virginia, and Virginia. Correlative units (Fig. 1) include the Cussewago Sandstone in western Pennsylvania and the lower Berea in eastern West Virginia (Potter et al., 1983). The Hanibal, Maury, and Chattanooga shales in western Kentucky are stratigraphic equivalents to the Bedford Shale (Rice et al. 1979; Milici et al., 1979).

The Ohio Shale-Bedford Shale contact records a sharp transition from anoxic bottom water conditions during Ohio Shale deposition to more oxygenated bottom water conditions during Bedford deposition. This interpretation has been proposed previously (Pepper et al., 1954; Hoover, 1960; Szmuc, 1970). Pepper et al. (1954) also proposed an alternate explanation, suggesting that the lithologic change across the contact may have been produced by a change in sedimentation type and/or rate. Evidence for each of the above interpretations was incomplete and/or unclear.

A detailed study of the Bedford-Berea sequence in central Ohio (Coats, 1988) concluded that the Ohio-Bedford transition records the onset of bottom water oxygenation. Evidence for this interpretation includes: 1) The lithologic changes across the boundary do not appear to result from sediment grain-size or compositional changes. The Ohio Shale and the Bedford Shale are qualitatively very similar in grain size, and the mineralogies of their silt and clay size fractions are also very similar. 2) Total organic carbon (TOC) values drop dramatically across the boundary, from 11-15% below the contact to virtually 0% immediately above the contact. TOC values remain near 0% throughout the rest of the Bedford (where sampled and analyzed). In general, sediments in modern oxygenated marine environments contain less than one percent TOC (Kennicutt et al., 1986). 3) The basal 30 cm of the Bedford Formation contain a relatively diverse and abundant benthic foraminifera population and an in-place, relatively low diversity, small macrofauna that primarily consists of brachiopods, mollusks, and gastropods. The presence of these body fossils within the Bedford Shale also indicates that oxygen was present at the sediment-water interface during Bedford deposition.

The Bedford Shale in the central Ohio area gradually coarsens upward, recording continued deposition of very fine-grained prodeltaic clastics in the western Appalachian Basin (Coats, 1988). Color changes within the Bedford Shale, especially the development of the "red Bedford", are diagenetic in origin. The thin, graded siltstone stringers (Fig. 4) found throughout the Bedford Shale are the distal ends of storm-generated turbidites. The turbidite siltstones thicken and become more numerous in the upper Bedford, recording the approach of a Berea Sandstone deltaic complex (Coats, 1988).

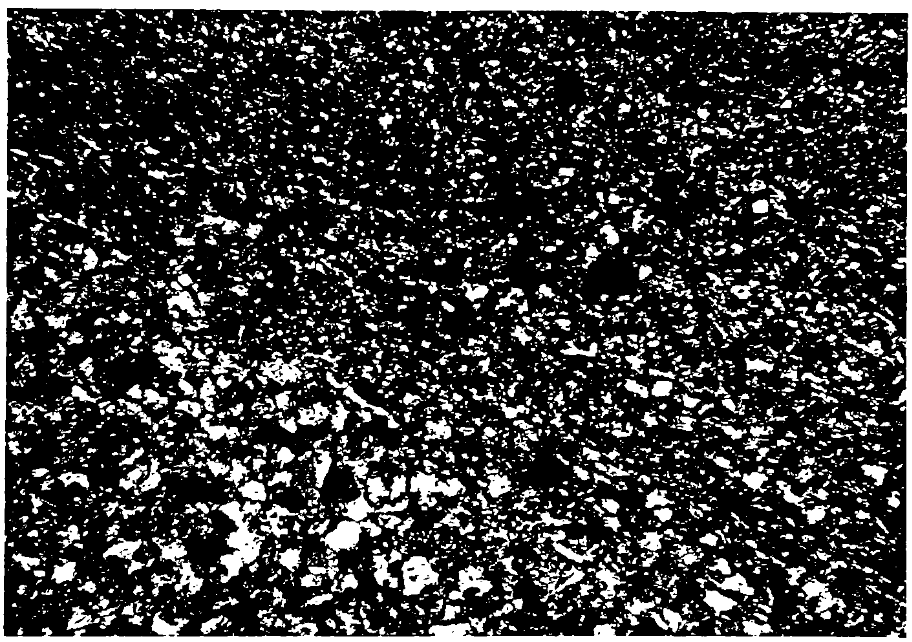

FIG. 4.-- Photomicrograph of thin siltstone from the Bedford Shale, grading from quartz-rich coarse silt to mica-rich medium silt. Stratigraphic top is to the upper right. Scale of photo is 1.3 mm.

Berea Sandstone.-- The Berea Sandstone is interpreted to be Early Mississippian in age because of its stratigraphic position above the Bedford Shale and below the Sunbury Shale. The nearly complete absence of body fossils in the Berea Sandstone, other than coalified plant debris, complicates the direct determination of its age.

The Berea was named by J. S. Newberry (1870) for sandstone exposures in cliffs at the town of Berea, in northern Ohio. The unit has been extensively studied in northern Ohio and southern Ohio and Kentucky since that time (see Potter et al., 1983, for a summary of past work). Thicknesses and lithologies of the Berea Sandstone are now known to be quite variable across Ohio. In northern Ohio, the Berea is a fine to coarse-grained, variably cemented sandstone approximately 25-30 meters thick. Localized sandstone bodies, however, are over 70 meters thick in this region. Pepper et al. (1954) interpreted the Berea in northern Ohio as part of a channelized deltaic system, discharging from the north, capped by a marine sheet silt-sandstone. Kohout and Malcuit (1969) interpreted the Berea in northern Ohio as a fluvially dominated deposit, discharging from the east. Potter et al. (1983) identified three major facies in the Berea of northern Ohio. The first is a basal sandstone, which occurs in crossbedded channel-form bodies that have eroded into, and in some places completely through, the Bedford Shale. Some of these channel-form bodies are also modified by soft-sediment deformation and syndepositional faulting (Lewis, 1988). The middle facies contains large festoon crossbedding up to 13 m long (Coogan, 1985), while the upper facies is a massive sheet sandstone with oscillatory ripple marks, of probable marine origin.

In central and southern Ohio, the Berea lithofacies is a coarse siltstone to a very fine sandstone. Its thickness is 20-25 meters near Sunbury, thinning southward to one meter or less near Lithopolis. South of Lithopolis the unit thickens again, reaching an average of five to ten meters (Hyde, 1953). Pepper et al. (1954), Potter et al. (1983), Pashin and Ettensohn (1987) and Coats (1988) have all interpreted the Berea of central Ohio and southern Ohio and Kentucky as a marine sheet sandstone deposited in shallow shelf and marine deltaic environments. The bedding features, sedimentary structures, and depositional environments of the Berea Sandstone in central Ohio are discussed in detail below for the Rocky Fork location visited on this trip.

The Berea Sandstone extends from Michigan, Ohio, and extreme western Pennsylvania to Kentucky, West Virginia, and Virginia. The Hanibal and Maury shales in western Kentucky and Tennessee are stratigraphic equivalents to the Berea Sandstone (Rice et al. 1979; Milici et al., 1979).

The Berea Sandstone in central Ohio is composed of marine, storm-dominated delta-front sediments, and continues the pattern of shoaling and coarsening upwards begun in the underlying Bedford Shale (Coats, 1988). A Berea deltaic complex prograded southeastward, and stopped northeast of Columbus during the Early Mississippian (Fig. 5). Figure 6 is a paleogeographic reconstruction of the western Appalachian Basin at the time of maximum progradation of the Berea Sandstone deltaic complex.

Sunbury Shale.-- Overlying the Berea Formation in sharp but conformable contact is the Lower Mississippian Sunbury Shale. This shale contains conodonts and macrofossils of Kinderhookian age (de Witt, 1970). The Sunbury Shale was named by L. E. Hicks (1878) for a small exposure found "by a systematic search of a day and a half" (Hicks, 1878) in Rattlesnake Creek, just southeast of Sunbury, Ohio.

The Sunbury is a black, organic-rich, fissile shale that is very similar in appearance to the Ohio Shale. Average thickness of this unit varies from five to ten meters. The Sunbury Shale is traceable in outcrop and the subsurface from Michigan across Ohio, Kentucky, and West Virginia, and into Virginia. In northeast Ohio and western Pennsylvania, the Sunbury is considered to be a member of the thicker Orangeville Shale. In western Kentucky and Tennessee, the Rockford Limestone and Maury Shale are correlative units to the Sunbury Shale.

The transition from the fine sands and abundant sedimentary structures of the Berea Formation to the very fine-grained clastics of the Sunbury Shale is sharp and distinct. The Sunbury Shale is interpreted as the deposit of a quiet-water, anoxic environment, suggesting that a rapid and significant relative rise in sea level occurred between Berea and Sunbury deposition. Such a relative rise in sea level would have trapped coarser sediments to the north and deepened the water column in central Ohio, thereby establishing bottom water conditions similar to those that existed during deposition of the Ohio Shale in the Late Devonian (Coats, 1988).

LOCALITIES

Stop #1, Camp Lazarus.-- The trip begins from Orton Hall on the Ohio State University campus. We proceed north on Ohio State Route 315 across the Franklin County/Delaware County line. Bluffs along the road, especially north of the intersection of Route 315 and Interstate 270, are composed of Ohio Shale. We turn east at Hyatts Road, cross the Olentangy River and then immediately turn north on Chapman Road. We proceed northward on Chapman Road to Lazarus Run (Fig. 7). The total distance traveled is approximately 32 km (20 miles).

Camp Lazarus is operated by the Central Ohio Council of

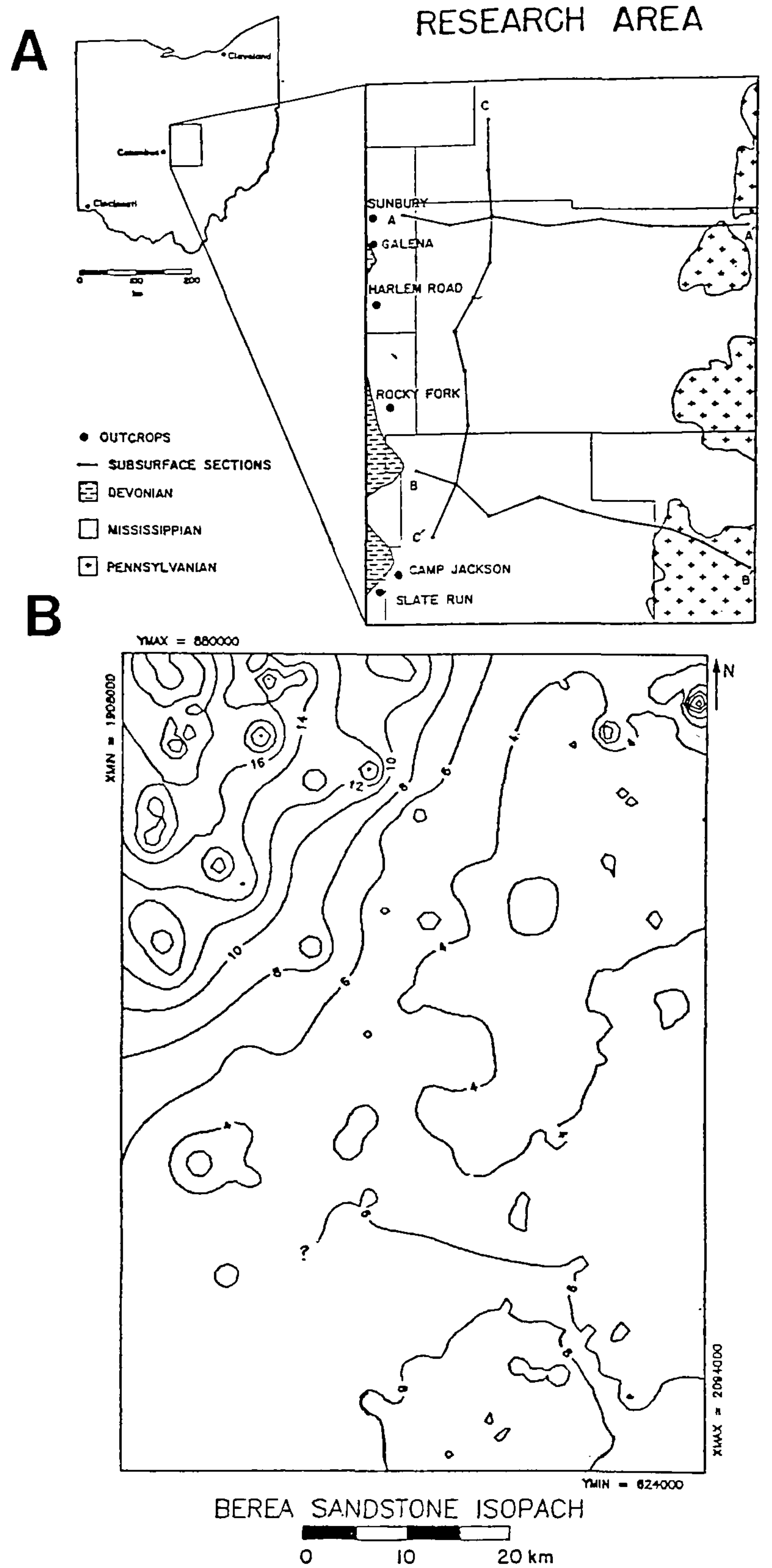

FIG. 5.--A) Research area of Coats (1988) showing location of B) Berea Sandstone isopach map. Contour interval is 2 meters. X and Y maximum and minimum are recorded in feet.

PALEOGEOGRAPHIC RECONSTRUCTION

(KINDERHOOKIAN)

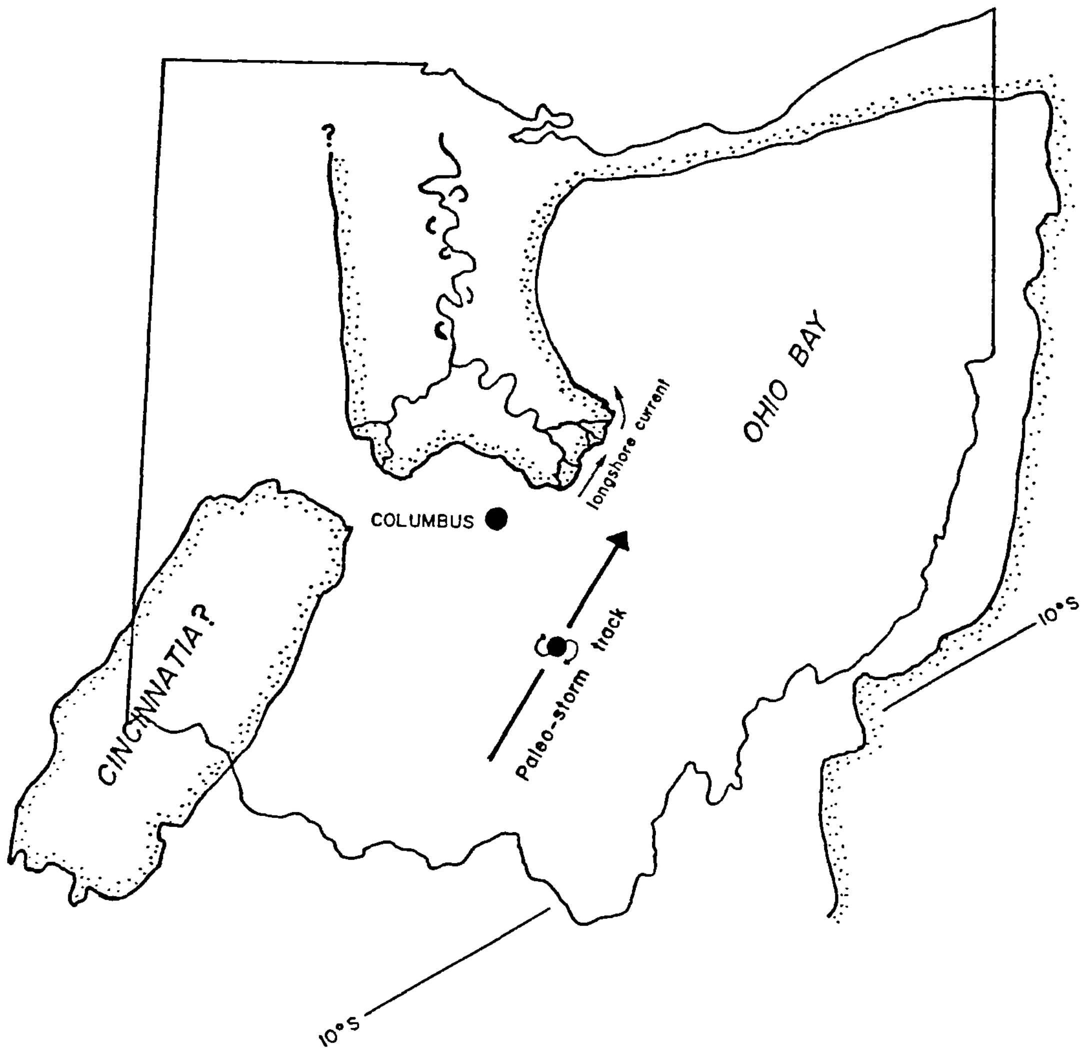

FIG. 6.--Paleogeographic reconstruction of the western Appalachian Basin (Coats, 1988).

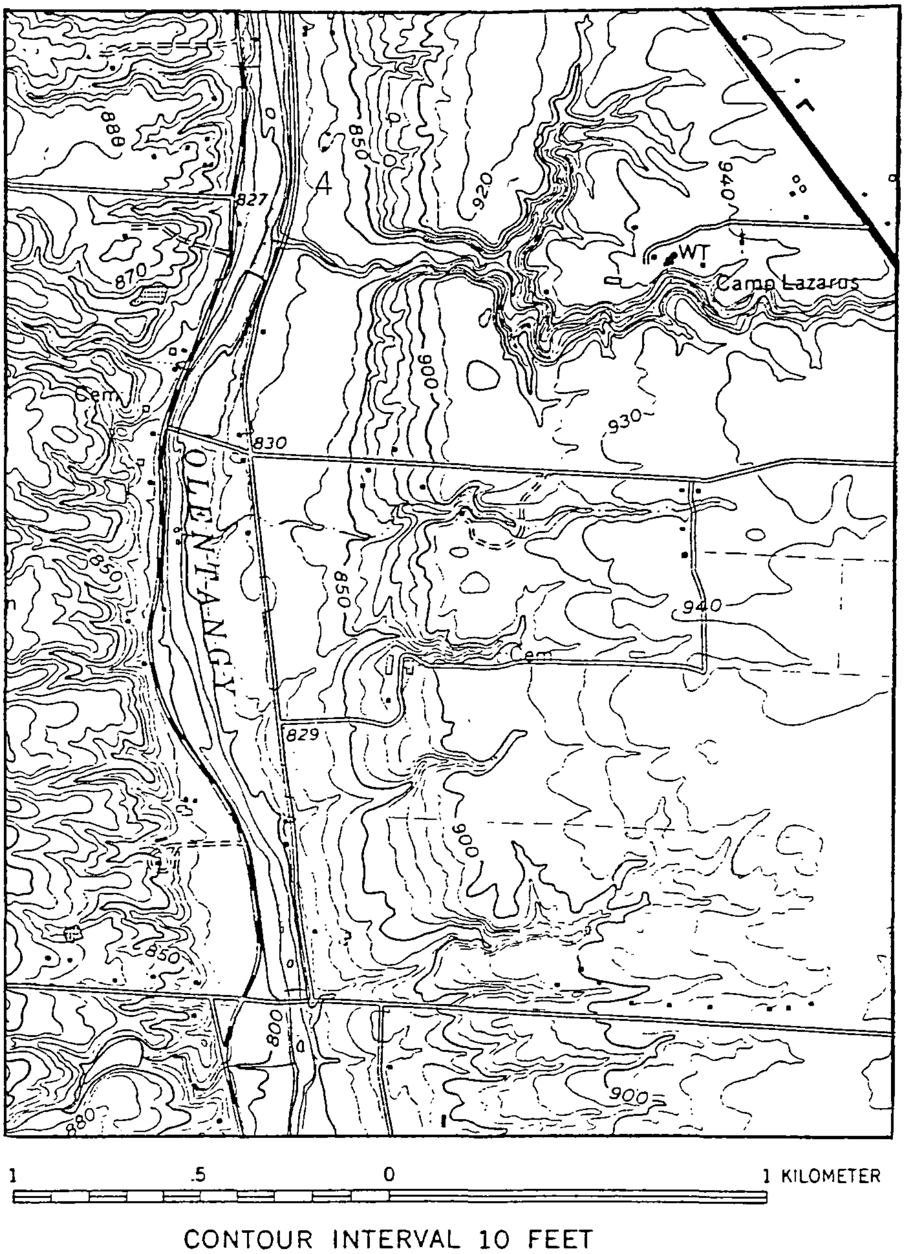

FIG. 7.--Camp Lazarus outcrop location map.

the Boy Scouts of America, and extends from U.S. 23 westward to the Olentangy River. The major entrance to the camp is located on U.S. 23, approximately two km (1.25 miles) east of the Olentangy River. The Lazarus Run section has been previously described and/or studied by Tucker (1969), Conklin (1969), Westgate (1926), and Stauffer (1909).

Beginning at river level, we will walk up Lazarus Run through the Delaware Limestone and Olentangy Shale to the lower Ohio Shale (Fig. 8). The eastern bank of the Olentangy River exposes the uppermost 30 cm of the Columbus Limestone and three to four m of Delaware Limestone. The exposure along the river is in the form of a small broad anticline. A thin (<five cm) "bone bed" of fish teeth and bone locally caps the Columbus Limestone, but is not obvious at this exposure. The bone bed is well-exposed, however, at other small outcrops nearby (W.I. Ausich, 1988, personal communication).

The Delaware Limestone is composed of thinly bedded, bioturbated (Fig. 9), silty, micritic limestones and shales that weather to a dirty brown color. The lower Delaware contains horizons of chert nodules, while the upper Delaware is more fossiliferous than the lower Delaware. The fossils found throughout the Delaware include a variety of corals, brachiopods, crinoid stems and tentaculitids; these fossils are most abundant in the upper portion of the Delaware (Tucker, 1969).

The Olentangy Shale is relatively poorly exposed throughout its outcrop belt because it weathers to a non-resistant plastic clay. Best exposures of the Olentangy Shale at Lazarus Run are found at, or just above, water level on cutbanks of the stream. Several thin beds of nodular limestone and black shale within the Olentangy are much more resistant and easy to identify in the stream bed. The limestone beds generally contain pyrite-filled burrows. One of the black shale beds contains abundant coalified plant material (Tucker, 1969).

The Ohio Shale caps the section at Lazarus Run. The Ohio Shale is a very resistant, fissile shale compared to the underlying Olentangy Shale, and forms the hills along the east side of the Olentangy River in the Columbus area. We only observe the lower portions of the Ohio Shale at this location, but the portion exposed contains abundant concretions, which are one of the most distinctive lithologies in the lower Ohio Shale (Fig. 10). The concretions are composed of carbonates and sulfides, and are described by Clifton (1957), Barth (1975), and Coats (1984). The concretions occur in a wide range of sizes, and are commonly centered on an organic nucleus. Concretions in the Ohio Shale have yielded an excellent record of Devonian fish, including the discovery of <u>Dinichthys hertzeri</u> in 1986. The origin of these

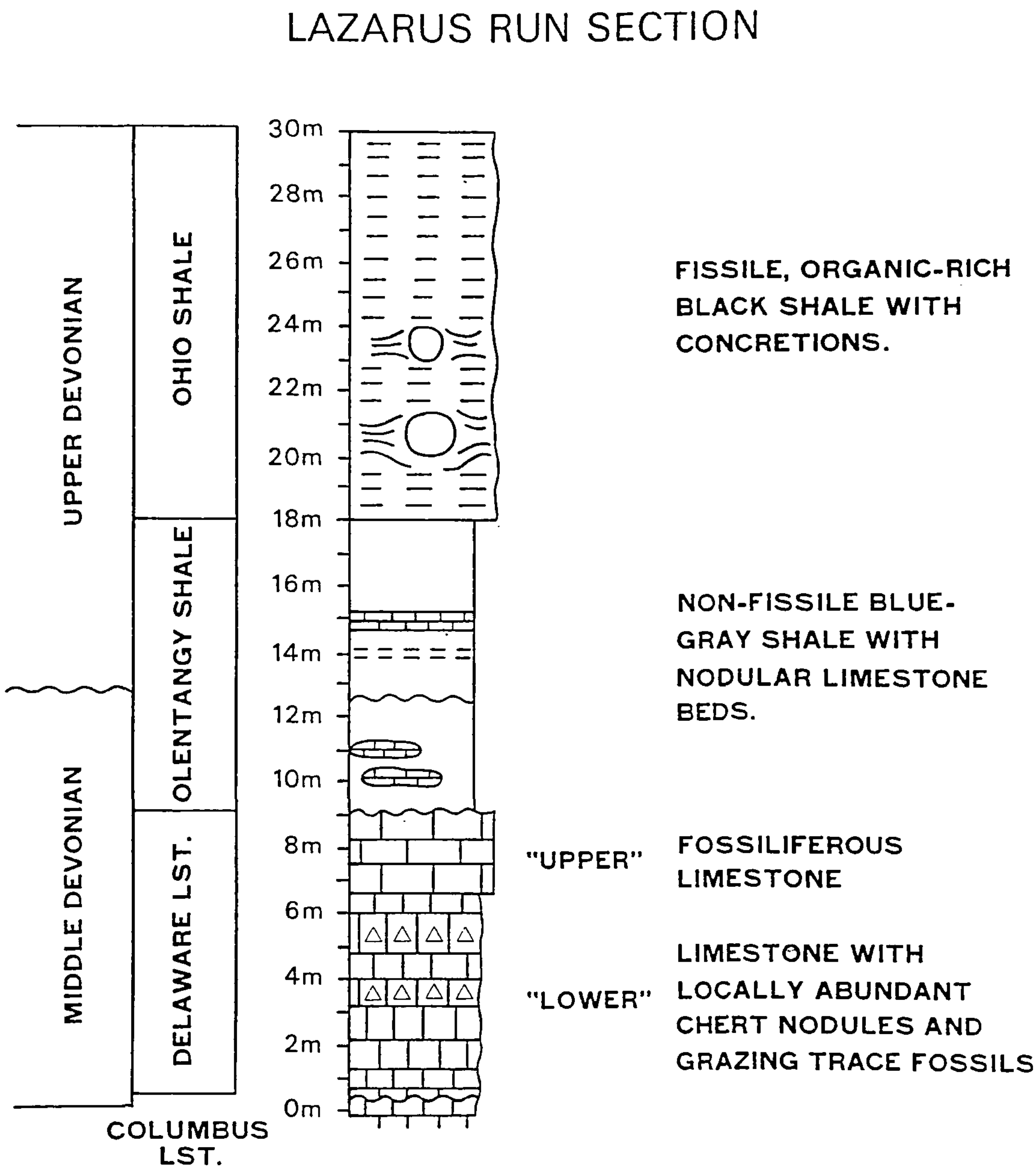

FIG. 8.-- Lazarus Run stratigraphic section.

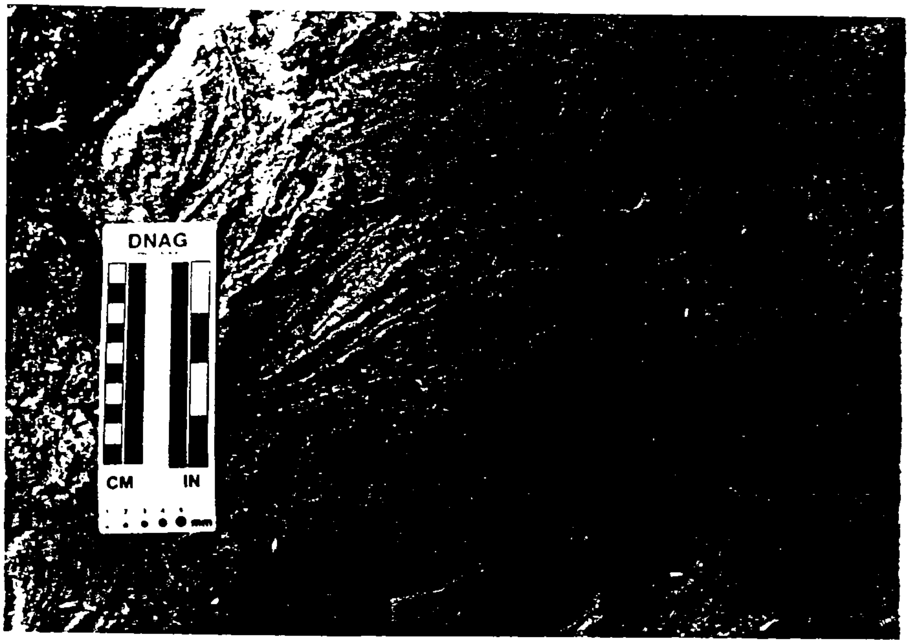

FIG. 9.-- Grazing trace fossil in Delaware Limestone, Lazarus Run.

FIG. 10.-- Ohio Shale outcrop with abundant concretions, Lazarus Run. Scale is 1.5 m.

concretionary bodies has been debated for some time; no recent studies have investigated the origin of the Ohio Shale concretions (to the best of the authors' knowledge).

<u>Stop #2, Galena</u>.-- From Lazarus Run, we travel generally east on Cheshire and South Galena Roads to the town of Galena (Fig. 2). In doing so, we cross Alum Creek Reservoir (a major recreational resource in central Ohio), cross Interstate 71, and skirt the north end of Hoover Reservoir (another major recreational area in central Ohio, and a major source of water for the city of Columbus). The total distance travelled is approximately 23 km (14 miles). This stop will be relatively brief, and will examine the Ohio Shale-Bedford Shale contact and the lower Bedford Shale. The units are exposed in the abandoned claypits of the Galena Brick Company on the east and west sides of Joe Walker Road (Fig. 11).

The Ohio Shale is primarily exposed here along Big Walnut Creek on the western edge of the claypits, and is very similar to the Ohio Shale seen at Camp Lazarus. The overlying Bedford Shale, which was the source material for the brick company, is reddish-brown, weakly fissile, and much less resistant. The contact between the two formations is very sharp. The basal 30 cm of the Bedford contain a low diversity fauna of small brachiopods, molluscs, and gastropods. Preservation is generally moldic, although some shell material is still present. This fauna is characteristic of the Ohio-Bedford contact throughout Ohio and Kentucky (Hyde, 1953; Pepper et al., 1954; de Witt, 1970; House et al., 1986).

<u>Stop #3, Lunch</u>.-- Blendon Woods Metropolitan Park. From Galena we travel predominantly south on Sunbury Road for approximately 20 km (12 miles), and proceed east on State Route 161 (Dublin-Granville Road) approximately 1.5 km (0.9 miles) to Blendon Woods Metropolitan Park. This park, approximately 400 acres in size, is one of five large parks maintained near or outside I-270 by the Columbus Division of Metropolitan Parks. Attractions at Blendon Woods Metropolitan Park include nature trails (one of which is the Ripple Rock Trail, so named for limited exposures of the Bedford Shale and Berea Sandstone) and a pond for migratory waterfowl.

<u>Stop #4, Rocky Fork</u>.-- From Blendon Woods, we travel east on State Route 161 to Hamilton Road (approximately 2 km (1.2 miles)), turn south on Hamilton Road, and proceed approximately 7 km (4.2 miles) to Clark State Road. We then turn east on Clark State Road, and proceed approximately 2 km (1.2 miles) to the property of Mr. Wilbur Smith. The excellent exposures of the upper Bedford Shale, the Berea Sandstone, and the lower Sunbury Shale

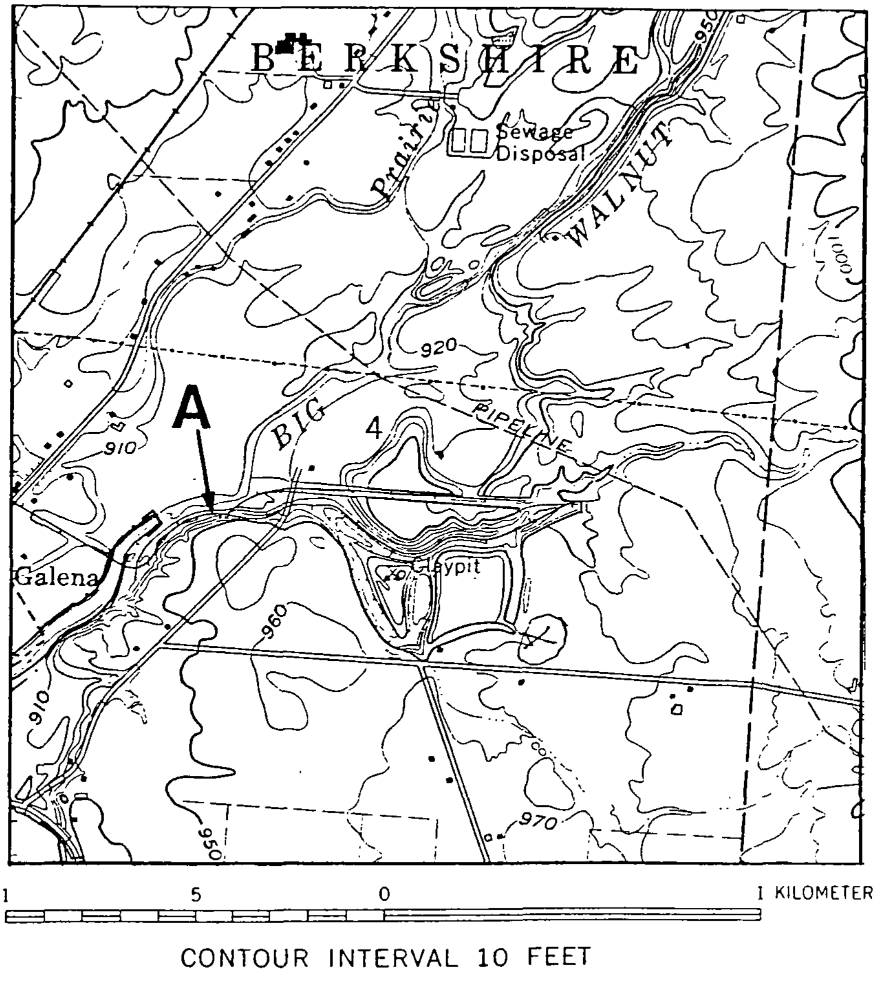

FIG. 11.--Galena outcrop location map. Point A identifies Ohio-Bedford contact exposure.

along Rocky Fork in Gahanna will comprise the final stop of this trip. Nearly continuous exposures are found along Rocky Fork, south of the Clark State Road bridge (Fig. 12). These exposures occur on the properties of Wilbur Smith and John Vorys, who have graciously provided access for our visits.

The section at Rocky Fork contains the only complete section of Berea Sandstone exposed between localities near Cleveland and outcrops in south-central Ohio. The measured section at Rocky Fork totals 18 m: 4.5 m of the upper Bedford Formation, 12.1 m of Berea Sandstone, and 1.5 m of Sunbury Shale (Fig. 13). The measured section begins at stream level at point A on Figure 12.

The upper Bedford Formation consists of interbedded silty shales and thin-bedded siltstones, with increasing siltstone content toward the top of the Bedford. This pattern is characteristic of the upper Bedford in the central Ohio area north of Gahanna (Coats, 1988). The shales are greenish to bluish-gray, occasionally weathering toward red. Laterally discontinuous starved siltstone ripples are common, generally with one siltstone layer every 5-10 cm within the shales.

Interbedded with the silty shales and the starved ripples are thicker (1-20 cm), laterally continuous siltstone beds (Fig. 14). These beds are commonly wave-rippled and contain horizontal burrows along their soles and between bedding planes (Fig. 15). The thicker beds contain low angle, low amplitude cross-stratification, and are laterally variable in thickness. The upper Bedford is interpreted as a delta-front body of fine clastics, with the episodic input of siltstones by the distal ends of storm-generated turbidity flows. As the delta front prograded, the siltstone beds thickened and became more numerous. The thicker units contain hummocky cross-stratification, indicating that deposition occurred at or just above storm wave base (Walker, 1984).

The Bedford-Berea contact is gradational at the Rocky Fork section. The very fine sandstones of the overlying Berea contain structures similar to those seen in the Bedford Formation. Bedding in the lower Berea is variable and complex, and is dominated by hummocky and swaley bedforms. Beds that are massive at one position grade laterally into several wave-rippled layers, and then either grade back into a massive bed or amalgamate with vertically adjacent beds. Bedding packages (50-80 cm thick) contain large (1-2 m wide) scours and adjacent swelling beds; beds within the packages contain low angle, low amplitude cross-stratification. The scours also contain wave-rippled beds that parallel the basal scour surface.

Soft-sediment deformation (Fig. 16) is present as flow rolls and contorted beds, and occurs both in isolated pods and in zones that extend laterally for more than 300 m.

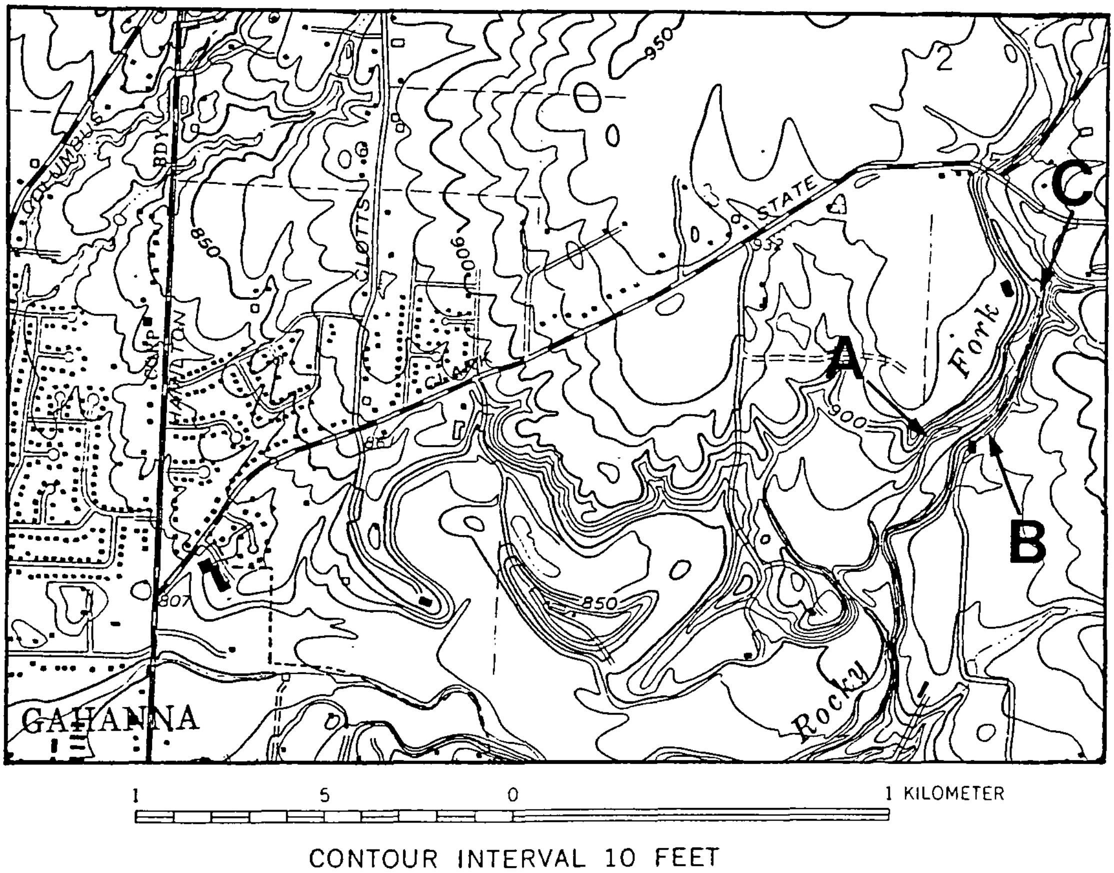

FIG. 12.--Rocky Fork outcrop location map. Labeled points referenced in text.

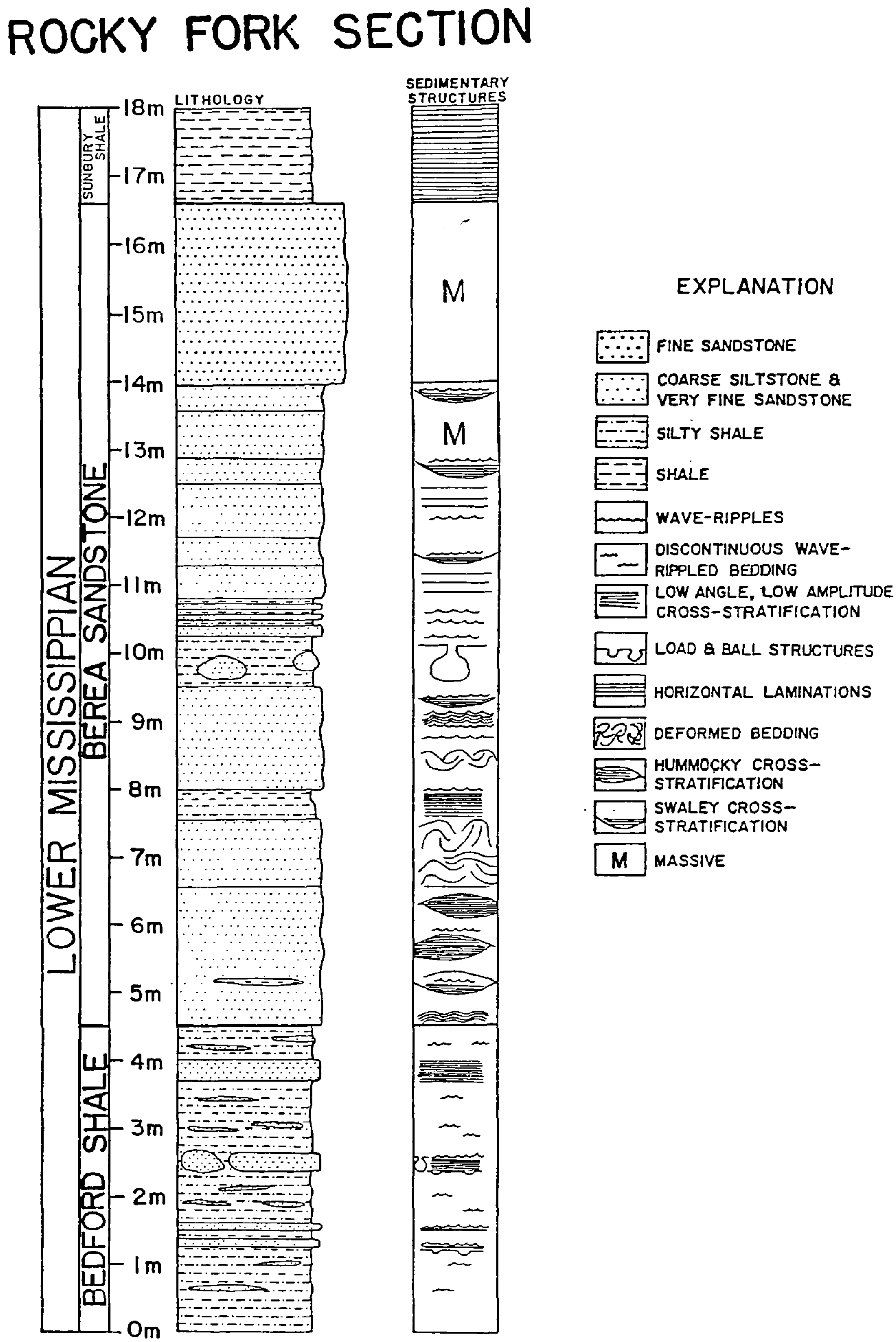

FIG. 13.--Rocky Fork stratigraphic section.

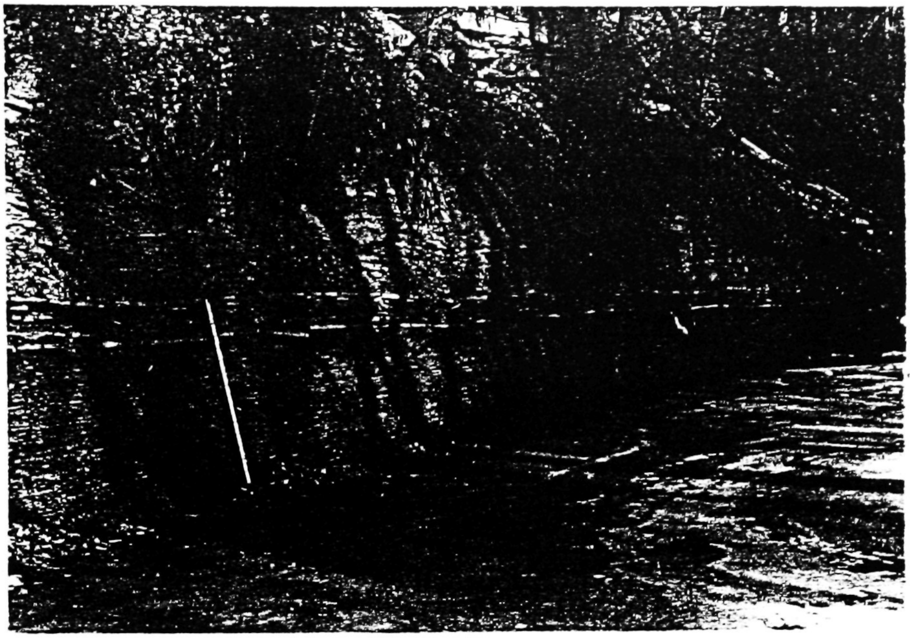

FIG. 14.-- Laterally continuous coarse siltstone beds in the upper Bedford Shale, Rocky Fork section. Scale is 1.5 m.

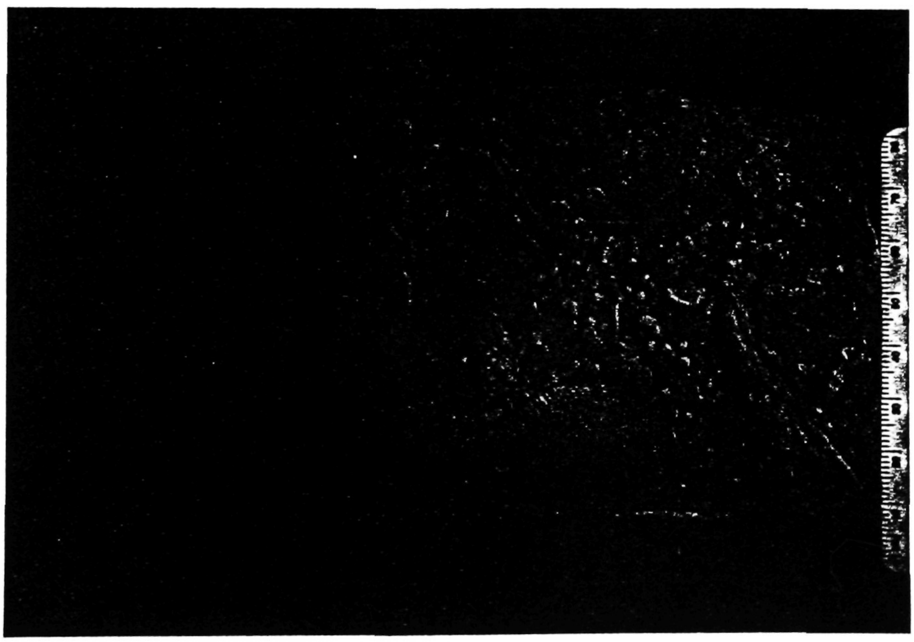

FIG. 15.-- Horizontal burrows and ?trilobite? resting trace, which are common on bedding planes and as sole marks on siltstones and very fine sandstones of the Bedford Shale and Berea Sandstone.

These structures were described by Cooper (1943). The zones of flow rolls can be traced from the highwalls into the stream bed because the flow rolls are relatively resistant to erosion, and usually form small cataracts.

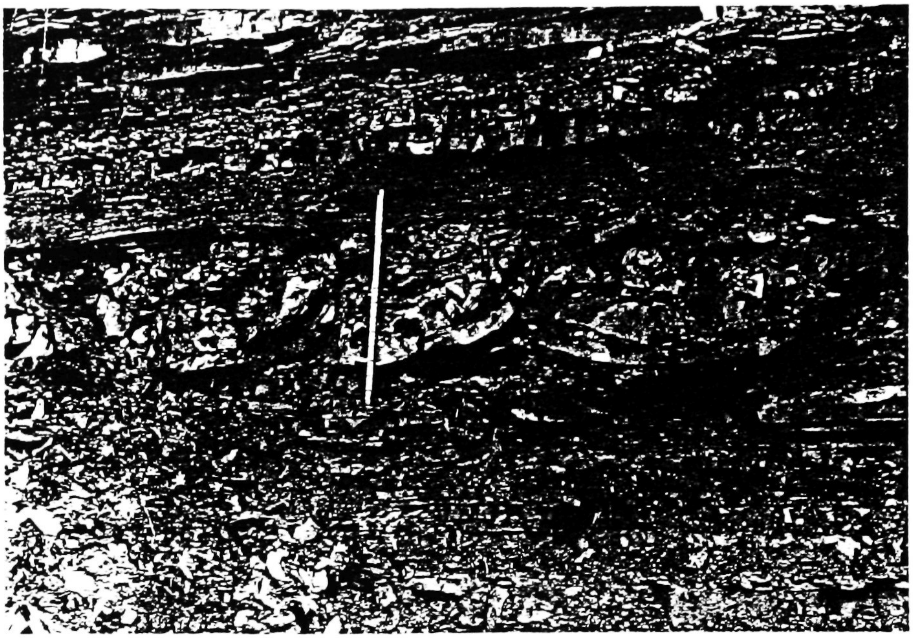

Fig. 16.-- Well-developed flow rolls in the Berea Sandstone, Rocky Fork section. Scale is 1.5 m.

Between highwalls B and C (Fig. 12), many bedding plane surfaces with abundant oscillation ripples are exposed in the stream. Crest orientations average N 55° W, but range from N 15° W to N 05° E. Paleocurrents from the ripple marks indicate a storm track to the northeast, which is at a right angle to the northwest-directed paleo-trade winds expected from the paleolatitude of this area in the Mississippian (Gutschick and Sandberg, 1983). The deflection of the storm track from the paleo-trade wind direction can be explained by the fact that this portion of the Appalachian Basin was surrounded by land on three sides, similar to the modern Gulf of Mexico. In the modern Gulf of Mexico, individual hurricane tracks vary extensively from the prevailing wind direction. A similar effect may have influenced storms crossing central Ohio during the Mississippian. Paleocurrent directions in the Bedford-Berea sequence show no vertical trends, suggesting that the sediments were positioned too far from shore for wave refraction to have occurred. The variability of paleocurrents within the Bedford-Berea, therefore, probably reflects the variable direction of individual storm tracks.

Near its top, the Berea sequence coarsens slightly to a very fine sandstone, as exposed in highwall C (Fig. 12); swaley cross-stratification dominates this exposure. Broad scours (1-3 m wide) are the dominant large scale features, and are filled with low angle, low amplitude cross-stratified sandstones with wave-rippled surfaces. Lateral bedding relationships are variable and complex (Fig. 17). Swaley cross-stratification is interpreted to form in shallower water, closer to fair-weather wave base, than hummocky cross-stratification (Walker, 1984). As a result, the transition from hummocky cross-stratification to swaley cross-stratification upsection is interpreted to record a shoaling-upward sequence in this portion of the Berea.

The top of the Berea at highwall C is composed of a massive fine-grained sandstone approximately 2.5 m thick. The massive appearance of this sandstone is produced by better sorting than in the strata below. The slight grain size increase and the well-sorted nature of this interval suggest deposition under relatively higher energy conditions than those producing the swaley cross-stratification immediately below. Such conditions could occur at or just above fair-weather wave base, so that the uppermost Berea records the continued shoaling of this area. The Berea is sharply overlain by the Sunbury Shale, a black, fissile, organic-rich shale that is similar in appearance to the Ohio Shale.

SUMMARY: THE BEDFORD-BEREA DEPOSITIONAL MODEL

The Bedford-Berea sequence in central Ohio records marine, prodelta and delta front deposition in the western Appalachian Basin during the Early Mississippian. The sequence begins with an oxygenation event of the bottom waters, which is recorded by the Ohio Shale-Bedford Shale contact. Macrofauna is only present at the base of the Bedford Shale, which may reflect the development of oxygenated environments on top of the organic-rich sediments of the Ohio Shale. Paleoenvironments throughout the rest of the Bedford Shale appear to have been inhospitable to a macrofaunal community.

Lithofacies changes in the Bedford Shale do not result from changes in its provenance, because the mineralogy of the Bedford Shale is uniformly dominated by quartz, illite, and kaolinite. Color changes, especially in the lower Bedford, are diagenetic in origin. Dark green to gray

UPPER ROCKY FORK OUTCROP

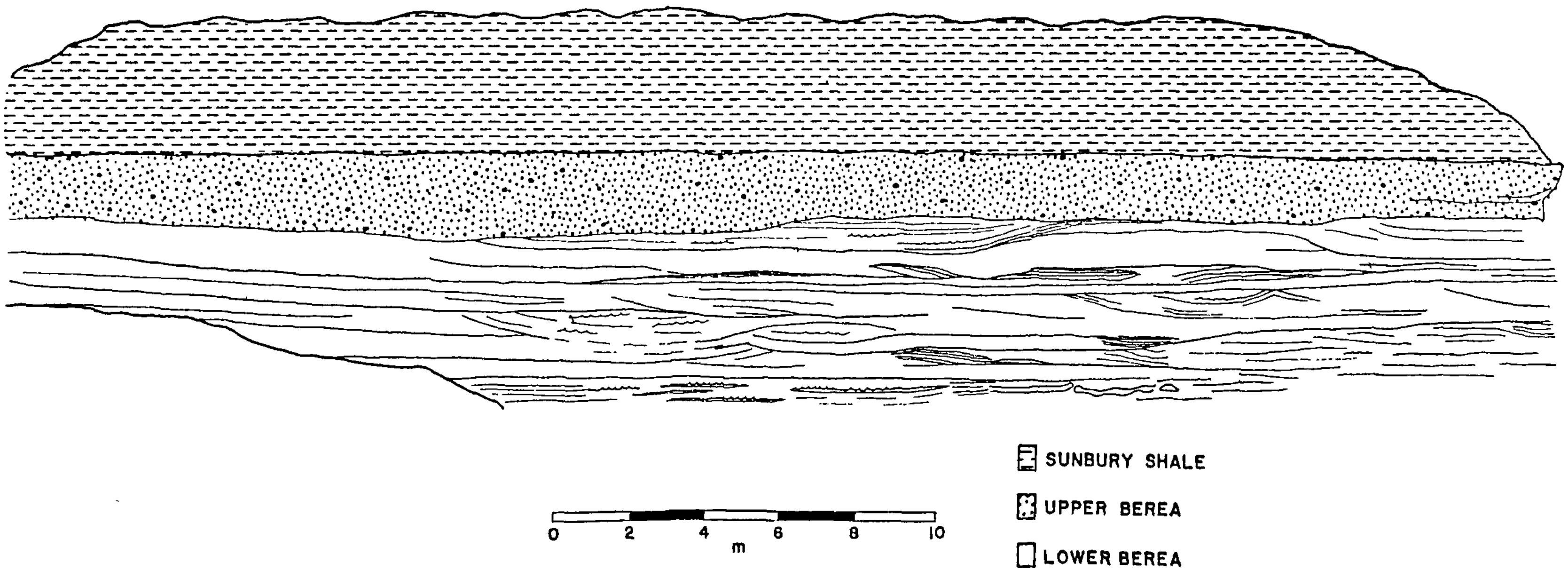

FIG. 17.--Variable and complex bedding relationships occurring in the upper portion of the lower Berea.

intervals contain minor amounts of chamosite, a probable authigenic Fe-rich chlorite, while the "red" Bedford intervals contain hematite but no chamosite. Oxidation of chamosite in modern marine sediments produces "red muds" (Carroll, 1970). The hematite in the "red" Bedford is interpreted to have formed in a similar fashion. The pH and redox conditions present during such diagenesis may also have controlled the dissolution of benthic foraminifera in the Bedford.

The upper Bedford is the transition zone from the underlying, very fine-grained Bedford sediments to the overlying, coarser Berea deposits. This interval is the first evidence of a supply of coarser sediments to the northern half of the study area by a prograding feeder system. The approach of this feeder system is recorded in two ways:

1.) The thin, graded siltstone stringers in this interval are interpreted as the distal ends of storm-generated turbidity currents. As the feeder system prograded, sediment input increased and the water depth decreased. The increased sediment input produced the upsection thickening of the siltstones. The shoaling water conditions moved the depositional surface above storm wave base, producing the hummocky cross-stratification and oscillation ripple marks observed in the upper Bedford.
2.) Isopach maps of the Bedford Shale in central Ohio show a significant decrease in Bedford thickness from north to south. This change suggests higher sedimentation rates of fine-grained clastics proximal to the northern feeder system.

Berea Sandstone isopach and structure contour maps (Coats, 1988) show that a deltaic system prograded to the south and east from the northwest corner of the study area during the Early Mississippian. This deltaic system is the proximal end of the sediment supply system described for the Bedford Shale. In north central Ohio, Berea Sandstone outcrops record a shoaling sequence of marine, storm-dominated, delta front sands. This interpretation is predominantly based on the upsection change from hummocky cross-stratification to swaley cross-stratification to a well-sorted, massive character. Petrographic data indicate that all of the Bedford and Berea silts and sands were derived from northern and northeastern sources.

The Bedford-Berea contact and the Berea Sandstone are strikingly different in south central Ohio, however. At these localities (not visited on this trip), the Bedford-Berea contact is very sharp, and the Berea Sandstone is a thin, hummocky-to-swaley cross-stratified unit. These differences are interpreted to result from the paleogeographic position of the deltaic complex relative to the paleo-storm track. The relatively consistent northeasterly storm track across the front of the delta produced a net sediment transport to the northeast. The localities in south central Ohio were south and slightly west of the deltaic lobe, however, so that storm-generated density flows were deflected away from the slightly deeper environments presently represented in south central Ohio. This setting is illustrated in Figure 6.

The entire Bedford-Berea sequence was drowned in the transgression leading to deposition of the Sunbury Shale. As a result, the Bedford-Berea sequence exposed in central Ohio today records an important transition zone between Early Mississippian delta-dominated and more offshore environments.

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